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Biodegradable Edible Films Derived from Banana Peels Infused with Extract from Moringa Oleifera

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ABSTRACT

The edible film made from ripe banana peel starch (*Musa paradisiaca L.*) enriched with Moringa oleifera leaf extract as an antioxidant, offers a solution to the challenges faced by the modern food industry, which demands innovative and environmentally friendly packaging options to ensure food integrity and safety. The use of natural antioxidants such as Moringa oleifera plays a crucial role in neutralizing free radicals, which can degrade food quality and accelerate deterioration. The edible film of kepok banana peel starch (*Musa paradisiaca L.*), enriched with Moringa oleifera leaf extract at four different concentrations (1.5%, 2.0%, 2.5%, and 3.0%), will undergo characterization. These characteristics include tensile strength, elongation percentage, elasticity, thickness, water vapor permeability, functional groups, pH, biodegradability, water absorption capacity, solubility, shelf life, and antioxidant properties. The optimal treatment condition in this research involved using banana peel starch edible film with 2% (v/v) Moringa leaf extract. The film possessed tensile force of 1.35×10^{-2} N/mm^2, elongation percentage of 129.76%, elasticity of 1.04×10^{-2} Kgf/mm^2, water absorption of 191%, solubility of 79%, rate of water vapor transmission for 1.647 g/h.m^2, and a 5-day shelf life at ambient temperature. FTIR analysis revealed that the edible film was produced via physical mixing, without the formation of new functional groups. The biodegradability test demonstrated that the edible film was capable of decomposing within two days. The inclusion of Moringa oleifera leaf extract enhances the edible film by improving its antioxidant properties, thereby providing better protection against food oxidation.

1. INTRODUCTION

Innovative and sustainable packaging methods are needed to address the issues faced by the modern food business in maintaining the integrity and security of food products [1]. One of the continent's advancements in this area is the development of edible films, which are thin, food-grade films utilized for packaging food products. Thin films and edible coatings maintain the quality and nutritional value of fruits and vegetables without altering them [1, 2].

Kepok banana (*Musa paradisiaca L.*) peel is a viable source of raw materials for producing edible film. Kepok banana peels are often considered an unused agricultural byproduct [3]. Kepok banana (*Musa paradisiaca L.*) is a tropical fruit with high nutritional value, particularly rich in fiber and potassium. It is easy to cultivate and has significant production value, generating a considerable amount of banana peel waste [4]. Banana peels have a fairly good amount of carbohydrates, fats, proteins, minerals, and vitamins. Despite having a high starch content of around 18.5%, banana peels show great potential for use in edible film production [5].

To improve the effectiveness of edible films, it is essential to refine the qualities of the coatings for contemporary applications. The type and amount of plasticizer significantly influence the characteristics of films [6, 7]. Plasticizers are typically small molecules, such as polyols like sorbitol and glycerol. They are known to disperse and insert themselves among polymer chains, leading to the disruption of hydrogen bonds and the separation of the polymer chains. This process enhances flexibility while increasing water vapor and gas permeability [8, 9].

Edible films based on banana peels often face oxidation and discoloration issues, which affect the quality of food products. Incorporating antioxidants is a promising strategy to enhance the stability and longevity of these films. Moringa oleifera L. leaf extract is a source of natural antioxidants that has recently attracted attention in research. Phytochemical analysis of Moringa leaves (Moringa oleifera L.) reveals that they are rich in secondary metabolites, including saponins, flavonoids, alkaloids, and tannins. These compounds not only act as antioxidants but also exhibit antibacterial properties, making Moringa leaf extract a promising additive for enhancing the properties of banana peel starch-based edible films in this study [10]. Moringa oleifera L. is a plant abundant in South Asia, especially in Indonesia, and is rich in antioxidant compounds. This plant is generally consumed by the Indonesian people. However, research on the use of this plant extract in films for food packaging is still limited. Based on the description above, this study developed a combination of edible film from banana peel and Moringa leaf extract as an antioxidant, with the aim of increasing the oxidative stability and mechanical characteristics of the edible film. The incorporation of Moringa leaf extract as an antioxidant in edible film production adds value to banana peel processing and makes use of abundant local natural resources. Additionally, this study aims to determine the physicochemical properties of the resulting film.

2. METHOD

In this research, the edible film of kepok banana peel starch (*Musa paradisiaca L.*) enriched with Moringa leaf extract (*Moringa oleifera*) was prepared and characterized. The characterizations comprised: elongation percentage, tensile strength, thickness, elasticity, and rate of propagation of water vapor, functional groups analysis, pH measurement, biodegradability, water absorption capacity, solubility, shelf life, and antioxidant properties. The preparation and characterization in this study were based on previous studies on edible films.

2.1 Sample preparation

2.1.1 Extraction of kepok banana peel starch

2 kilograms of kepok banana peels were washed. Additionally, the kepok banana peel was chopped into small pieces and washed thoroughly with running water. Small pieces of kepok banana peel were blended in a blender at a low speed. The blender was filled with a 0.0230% solution of sodium bisulfite (2.3 grams of sodium bisulfite diluted in 2 liters of distilled water). The mixture was squeezed using a thin porous cloth. The leftover sediment was removed and the filtrate was left undisturbed for 24 hours. After removing the sediment from the filtrate, distilled water was used to rinse it, and a Buchner filter was used to filter the material [11]. After that, the precipitate was fully dried for 12 hours at 50°C in an oven. To produce kapok banana peel starch, the precipitate was combined, mashed, and sifted through a 100-mesh screen after drying.

2.1.2 Extraction of Moringa leaves

The Moringa leaves were dried and then ground into a powder. 5 grams of Moringa leaf powder was weighed. 100 mL of a solvent mixture containing ethanol and water (50:50) was poured into the Moringa leaf powder in an Erlenmeyer flask, and then sealed. For a whole day, the maceration procedure was conducted at room temperature. After filtering the Moringa leaf extract, a rotary evaporator was used to concentrate the filtrate [12].

2.1.3 Fabrication of edible film

Edible films were prepared by using 3 grams of starch from kepok banana peels and then placed into a glass container. A 2% (w/v) of Sorbitol solution and extracted Moringa leaves (with various concentrations of 1.5%, 2.0%, 2.5%, and 3%) were added. A magnetic stirrer was used to keep the solution at 80°C for 15 minutes while it was heated on a hot plate with 80 mL of distilled water added. Subsequently, 20 milliliters of distilled water containing one gram of CMC was added to the starch mixture. The heating continued at 80°C for an additional 7 minutes. The solution was cast into a glass mold of 25 × 20 × 2 cm. After that, the cast solution was allowed to dehydrate for eighteen hours at 50°C in an oven, and then it was allowed to cool for ten minutes. The thin film was then carefully removed using a spatula and placed in a desiccator for storage [13, 14].

2.2 Analysis of edible film

2.2.1 Test for edible film thickness

Five distinct places were used to quantify the thickness of each edible film using a digital micrometer with an accuracy of 0.01 mm. The average was measured as the film thickness result [14].

2.2.2 Elasticity, elongation percentage, and tensile strength measurement

The Universal Testing Machine was utilized to assess the mechanical characteristics of the films. The sample was fastened to the grip at both the top and bottom in order to do the analysis. Before beginning the test, which was done by turning the UP knob, the recorder was reset to zero. After finishing, the grip was put back in place by pressing the RETURN button. A sample size of 80 mm by 40 mm and a pulling speed of 700 mm/minute were employed in the test, a gripping force of 50 N/5 Kgf, and a sample area (A) of 80 × 40 mm^2 [15].

2.2.3 Functional group analysis using Fourier Transform Infrared Spectroscopy (FTIR)

To examine the functional groups, FTIR was used to determine whether the reaction was chemical or physical. The sample was initially placed on the designated holder and then scanned. The resulting diffractogram showed the relationship between wavelength and intensity level. Room temperature was used to record the FTIR spectrum [16].

2.2.4 Data analysis of field emission scanning electron microscopy (FESEM)

Using a Thermo Scientific Quattro S at 5 kV, field emission scanning electron microscopy (FESEM) was used to analyze the surface morphology of the films.

2.2.5 pH measurement

A pH meter was used to perform the test. One gram of the edible film was dissolved in ten milliliters of distilled water in order to do the measurement. The electrodes of the pH meter were placed into the solution, and the pH value was measured afterward [17].

2.2.6 Biodegradability test

The biodegradability test, which assesses the ability of the bioplastic to break down, was performed by putting the edible film into the Effective Microorganism 4 (EM4) solution. The edible films, cut into 2 × 2 cm pieces, were immersed in an EM4 solution containing bacteria within a petri dish and observed until they were entirely decomposed. EM4 contains various microorganisms, including lactobacillus, fungi, bacterial actinomycetes, common soil organisms include yeast, phosphate-solvent bacteria, and photosynthetic bacteria [16].

2.2.7 Water absorption test

To begin the water absorption test, two grams of edible film had to be weighed (D). The sample was then submerged in distilled water for 10 seconds. After removal, excess water on the film's surface was blotted with a tissue, and the sample was reweighed. Until a constant weight (final weight, C) was attained, this process was repeated [16].

2.2.8 Edible film solubility test

For the solubility test, 2 grams of edible film were first weighed and then dried in an oven at 100℃ for 30 minutes to obtain the initial weight (B). The film was then soaked in distilled water for 24 hours. After soaking, the film was dried in the oven for 2 hours at 100℃ and placed in a desiccator for 10 minutes. Finally, the film was weighed to determine the final weight after immersion (D) [16].

2.2.9 Water vapor transmission rate (WVTR)

The WVTR of each film was assessed to evaluate their barrier properties against water vapor. A desiccator was conditioned to 75% relative humidity using a 40% NaCl salt solution. Three grams of the edible film were used to seal a porcelain cup containing five grams of activated silica gel. After being weighed, the porcelain cup was put inside the desiccator. The WVTR was measured every hour for five hours, and the rate was calculated [16].

2.2.10 Shelf-life test

The shelf life of sliced potatoes, both with and without edible film coverage, was evaluated under different conditions. Three different packaging variations were used for the first treatment, which was kept at 30℃: K1 (no packaging), K2 (wrapped in edible film), and K3 (wrapped in oil paper). The second treatment was kept in two different packing conditions—K0, which had no packaging, and K1, which had edible film wrapped around it—at 16℃ [18].

2.2.11 Antioxidant test

The extract's antioxidant activity was assessed using UV-Vis spectrophotometry utilizing DPPH reagent. To reach a concentration of 1000 ppm, a 10 mg sample of the extract was diluted in 10 mL of volumetric flask ethanol. There were additional dilutions of this solution to 20, 40, 60, 80, and 100 ppm. After homogenizing 1 mL of each solution with 3 mL of 50 μM DPPH solution, the mixture was placed in the dark for half an hour. Regression analysis was used to calculate the IC50 value and the percentage inhibition curve after absorbance was measured at 517 nm [19].

3. RESULT AND DISCUSSION

3.1 Research result

The edible films were created using different amounts of Moringa leaf extract. The samples were designated as M0, M1, M2, M3, and M4, representing edible films with varying concentrations of Moringa leaf extract (0%, 1.5%, 2%, 2.5%, and 3%, respectively). This investigation assessed the edible film's tensile strength, elasticity, elongation, thickness, and rate of water vapor transmission, FTIR functional groups, pH, biodegradability, water absorption capacity, solubility, shelf life, and antioxidant tests. The physical properties of an edible film made of starch and banana peel mixed with extract from Moringa leaves are shown in Table 1.

Table 1. Characterization of edible film

Parameter	Treatment				
	M0	**M1**	**M2**	**M3**	**M4**
Measurement of thickness (mm)	0.14	0.12	0.13	0.14	0.15
Strengthening of Tension ($N.mm^{-2}$)	0.0128	0.0125	0.0135	0.111	0.0111
Length (%)	150.19	99.84	129.76	70.3	103.83
Flexibility ($Kgf.mm^{-2}$)	0.0085	0.0125	0.0104	0.0157	0.0106
Water Vapor Transmission Rate ($g.^{-1}.m^{-2}$)	2,416	2.189	1.647	2.218	2,330
pH	6.88	6.81	6.82	6.79	6.81
Water Absorption Capacity (%)	215	233	191	184	190
Solubility (%)	74	79	79	72	60
Shelf Life (days)	5 days	5 days	5 days	5 days	5 days
Antioxidant IC 50 (ppm)	269,407	249,571	223,585	215,547	202,849

Note: M0 represents the sample with 0% Moringa oleifera extract, M1 denotes the sample with 1.5% Moringa oleifera extract, M2 refers to the sample with 2% Moringa oleifera extract, M3 refers to the sample with 2.5% Moringa oleifera extract, and M4 denotes the sample with 3% Moringa oleifera extract.

3.2 Discussion

3.2.1 Edible film thickness

Incorporating Moringa leaf extract at 1.5%, 2%, 2.5%, and 3% (v/v) concentrations were produced changes in the edible film's thickness, as indicated in Table 1. The variation in thickness may be due to the unequal distribution of the film during the molding process. The thickness of the edible film produced increased slightly as a result of the application of Moringa leaf extract. The difference was not substantial. The Moringa leaves were added in liquid extract form, which is why they had minimal impact on the total solids in the solution. A thicker edible film has a denser structure and a greater ability to resist gas migration [19].

3.2.2 Edible film's elasticity, percent elongation, and tensile strength

The edible film's tensile strength test results are shown in Table 1. The results showed that adding Moringa leaf extract at concentrations of 1.5%, 2%, 2.5%, and 3% (v/v) changed the film's tensile strength; the values obtained were 1.25×10^{-2} N/mm², 1.35×10^{-2} N/mm², 1.11×10^{-2} N/mm², and 1.11×10^{-2} N/mm², respectively. The extract with a 2% (v/v) concentration showed the maximum tensile strength. The thickness of the edible film directly affects its tensile strength; as thickness increases, intramolecular interactions are strengthened and the tensile strength increases as well. Additionally, a concentration of 2% of the extract may be the ideal amount to interact with the starch matrix. A larger concentration of the extract caused a small decrease in tensile strength.

3.2.3 FTIR-based functional group analysis

To determine which functional groups were in the edible film, FTIR was used. Figure 1 presents the findings. The graph displays the functional group identification results, indicating that the Kapok banana peel starch edible film with and without Moringa leaf extract have comparable functional groups. The shared traits suggest that no novel functional groups were created, and the inclusion of Moringa leaf extract simply resulted in physical interactions. The higher and more intense peak at 3200 – 3600 cm^{-1} indicates O-H stretching, implying increased hydrogen bonding between the phenolic compound, CMC, sorbitol, and the matrix in the extract. The FTIR spectra of the films with Moringa leaf extract displayed phenolic groups at 3280.91 cm^{-1}, a C=C alkene group at 1632.36 cm^{-1}, a C-H alkane group at 2917.17 cm^{-1}, and a C-O ether group at 1048.19 cm^{-1} [20].

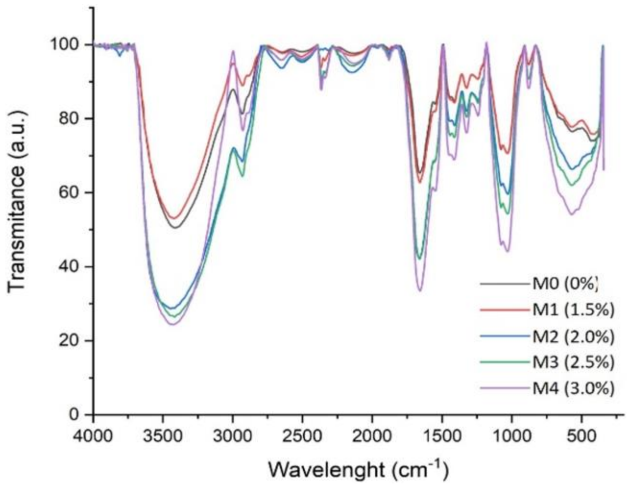

Figure 1. The FTIR spectra of films containing various concentration of Moringa extract

3.2.4 Surface characteristics of the films

The morphology of the film surface was analyzed using FESEM. The MO film without any Moringa leaf exhibited a dense structure with no cracks. Nevertheless, other films containing Moringa leaf extract extract (M1, M2, M3, and M4) showed noticeable fractures, and some parts of the surface films were blown and expanded, leading to the formation of a rough surface as shown in Figure 2. The roughness and the cracks of the film surface were more prominent at higher concentrations of Moringa leaf extract particularly at 500x magnification. The development of hydrogen bonds between the hydrophilic components of the films can be linked to the existence of fractures and roughness on the film surfaces [20]. Upon observation, it was noted that all films exhibited little white granules that are present on their surface, suggesting the presence of insoluble dietary fibres of the banana peel.

3.2.5 pH

The study results show that adding Moringa leaf extract resulted in an acidic edible film with a pH below 7, as demonstrated in Table 1. The interaction between the active components of Moringa extract and other substances decreased the pH of the edible films. Active components in Moringa leaves, including anthocyanins, flavonoids, and hibiscus glucosides, function as antioxidants. Antioxidant chemicals act as hydrogen donors, increasing the concentration of hydrogen ions in the edible film [21].

3.2.6 Biodegradability

The test findings indicated that the kepok banana peel starch edible film, when combined with Moringa leaf extract, totally destroyed in 2 days when exposed to EM4 Bacteria solution (Figure 3). EM4 contains microorganisms capable of decomposing polymer chains into monomers. Kepok banana peel starch is a naturally occurring, biodegradable polymer that decomposes quickly in the presence of bacteria and other germs. It was found that the edible film generated in this study was more environmentally friendly than synthetic plastic, which takes fifty years to decompose [22].

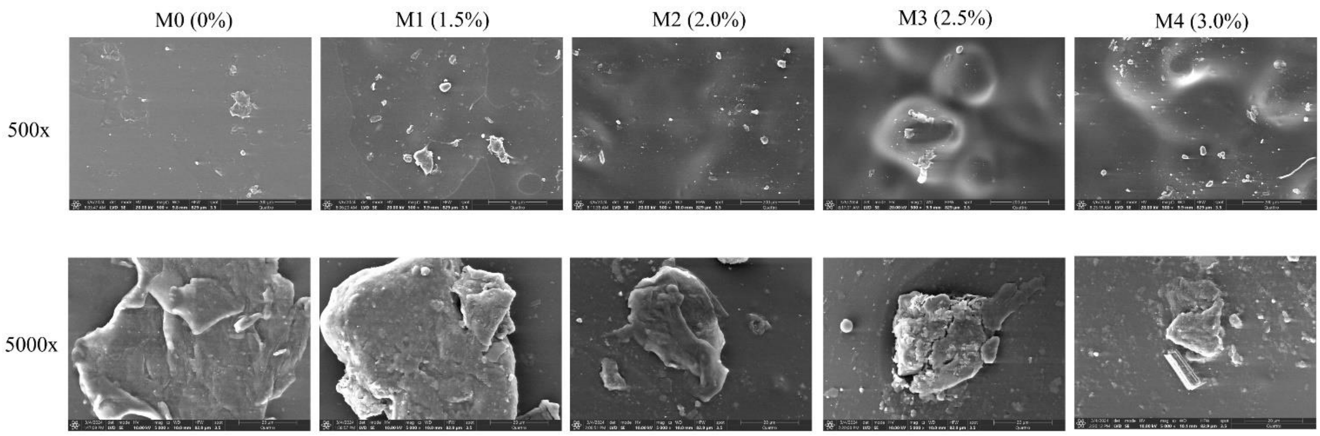

Figure 2. The morphology of the films surface containing different concentration of Moringa leaf extract

Table 2. The shelf life analysis of potato slices with and without film wrapping

No.	Usage for Potatoes	Temperature Room (°C)	Shelf Life (days)	Physical Condition
1	Wrapped in *edible film*	16	6	Good, somewhat withered, not charred, and not moldy
2	Without Packaging	16	3	shriveled and slightly blackened
3	Wrapped in *edible film*	30	5	Not rotten, slightly wrinkly, and slightly darkened
4	Without Packaging	30	2	Shrinking, modest blackening and mild mold growth

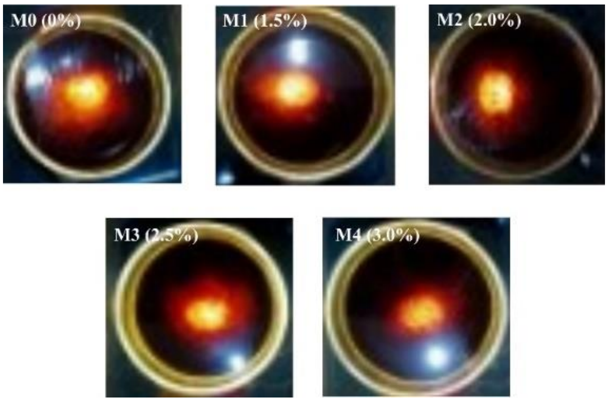

Figure 3. The process by which films with varying amounts of Moringa extract biodegrade

3.2.7 Water intake

The test for water absorption assessed the films' capacity to either absorb or repel water molecules. An edible film with good water absorption properties minimized water molecules intake. Various quantities of Moringa leaf extract in the edible film exhibit varying water absorption capacities, as shown in Table 1. Films containing 2.5% (v/v) Moringa leaf extract exhibited the lowest water absorption and superior water resistance compared to the other films. Incorporating Moringa leaf extract can reduce the water absorption of the edible film by fortifying the polymer matrix's intramolecular hydrogen bonds, which results in a denser structure and improved water resistance [23].

3.2.8 Solubility

Film solubility data is presented in Table 1 demonstrates that the edible film's solubility dropped as the concentration of Moringa extract increased to 1.5%, 2%, 2.5%, and 3% (v/v). The extract exhibited the highest solubility at 1.5% and 2% (v/v) concentrations, while the lowest solubility was observed at 3% (v/v). The increased interactions between the active chemical in the extract and the starch matrix may have led to decreased water solubility, resulting in this observation. The edible film is made of hydrophilic elements, which makes it dissolve more readily in water. Because Moringa oleifera's phenolic components interact with other molecules to produce hydrogen bonds, adding Moringa leaf extract can decrease the edible film's solubility. This increase in hydrogen bonding results in a denser structure, which consequently lowers the film's solubility. An edible film with high solubility will be more easily consumed due to its improved digestibility [24].

3.2.9 WVTR

The pace at which water molecules seep through the films is referred to as WVTR. Increasing the extract concentration did not notably affect the edible films' rate of water vapor transmission. Thickness plays a crucial role in this aspect, as a thicker edible coating leads to a denser structure, improving its resistance to gas migration and offering better protection for the food. This result is in line with the Japanese Industrial Standard (1975), which establishes a maximum water vapor transmission rate of 10 grams per square meter per day for edible films.

3.2.10 Shelf Life

The shelf-life assessment involved the application of edible film to potato slices. Two treatments are conducted: storage at room temperature (30°C) with two packaging variants and in a refrigerated environment (16°C) with two packaging variations. Table 2 displays the findings of the shelf life test. The study findings presented in Table 2 indicate that potatoes stored in edible film can extend up to 6 days at 16°C and 5 days at 30°C. Potatoes enclosed with edible film have a longer shelf life compared to potatoes that are not packed. Potatoes can have a longer shelf life because to edible film. Adding Moringa leaf extract further extends the shelf life of edible film by using its antioxidants to prevent oxidation processes when storing food. Antioxidants are compounds that shield cells from the harm that free radicals, which are unstable molecules, can inflict. Free radicals damage lipids, proteins, and nucleic acids by oxidative damage. Antioxidant chemicals donate electrons to free radicals to restore them to a stable molecular state and prevent harm [25-28].

3.2.11 Activity of antioxidants

Using extract from Moringa oleifera, an edible film's antioxidant content is assessed using the antioxidant activity test. The DPPH technique and UV-Vis spectrophotometry at a wavelength of 517 nm are used to measure its activity. When antioxidant chemicals diminish DPPH, an organic molecule having unstable nitrogen turns from purple to yellow in hue. The extract's antioxidant potency is indicated by the IC50 value, which is the concentration of the extract needed to suppress radical activity by 50%. Using the equation $y = ax + b$, where sample concentration is on the x-axis and percent inhibition is on the y-axis, linear regression analysis is used to estimate the IC50 value. This relationship between sample concentration (ppm) and percent inhibition is established. Percent inhibition indicates the antioxidant capacity of the edible film by measuring its effectiveness in neutralizing DPPH radicals [29].

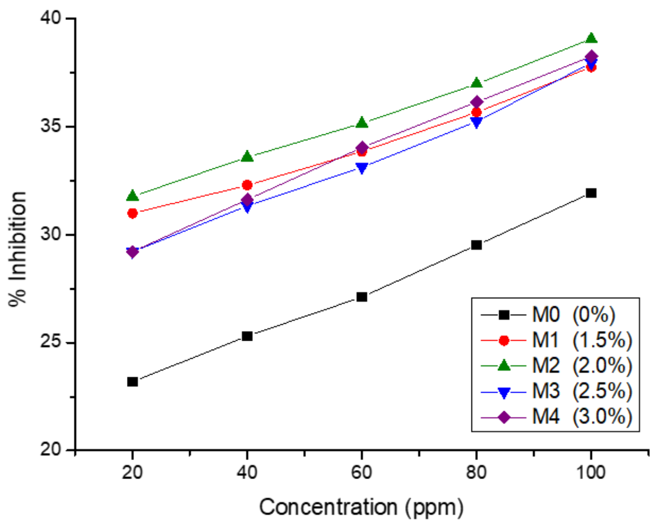

Figure 4. The % inhibition of the films containing different amount of Moringa leaf extract

Figure 4 shows the % inhibition of the films containing different concentration of Moringa leaf extract. It is observed that the film without Moringa leaf extract exhibited the lowest inhibition ability toward free radicals. At 20 ppm of extarct, the % inhibition of M0 was only 23%, and raised to 29% at 100 ppm. The % inhibition increased with the addition of Moringa leaf extract, particularly for M2 (2.0% extract). At 20 ppm, the % inhibition was 31.77% and raised to 39% at 100 ppm.

The study's results revealed a correlation between Moringa leaf extract concentration and increased antioxidant activity. Foods with 3% Moringa leaf extract showed the highest level of antioxidant activity (202.849 IC50), as shown in Table 1. According to reference [29], a lower IC50 value signifies greater antioxidant potential. An antioxidant is classified as It is classified as very strong if the IC50 value is less than 50 ppm, strong if it is between 50 and 100 ppm, medium if it is between 100 and 150 ppm, weak if it is between 150 and 200 ppm, and very weak if it is greater than 200 ppm. The edible film containing Moringa leaf extract exhibits relatively low antioxidant activity, as indicated by its IC_{50} value of >200 ppm. A larger concentration of Moringa extract is needed to enhance the antioxidant potential of the movies, since only 3% of the excerpt is deemed sufficient. The edible banana peel starch film, lacking Moringa extract, exhibited antioxidant components with an IC_{50} value of 269,407 ppm. Adding Moringa leaf extract enhanced the antioxidant content in the edible film made from kepok banana peel. The presence of flavonoid chemicals in Moringa leaves influences this. Flavonoid chemicals are polyphenolic constituents present in numerous plant species. Flavonoids can function as antioxidants. Adding Moringa leaf extract enhances the benefits of edible film, which acts as a food preservative by protecting it from oxidation.

The characterization results obtained in this research show that edible film from kepok banana peel and Moringa leaf extract not only has adequate physical and mechanical properties, but can also lengthen food products' shelf lives with better antioxidant protection. Thus, this research contributes significantly to the creation of cutting-edge, environmentally friendly food packaging technology, in accordance with the context discussed in the introduction.

4. CONCLUSION

The edible films derived from kapok banana peel contained various concentrations of Moringa leaf extract have been successfully prepared and characterized. based on an examination of the edible film's physical characteristics, it can be concluded that incorporating the extract from Moringa oleifera increases antioxidant activity, elongation, and the rate at which water vapor transmits. The relationship is inversely proportional to the water absorption capacity and solubility. At first, adding more Moringa oleifera extract improves pH, elasticity, thickness, and tensile strength. However, these characteristics may decrease under specific conditions or upon reaching saturation. The study's optimal treatment condition involved using banana peel starch edible film with 2% (v/v) Moringa leaf extract. The film exhibited tensile strength of 1.35×10^{-2} N/mm^2, elongation percentage of 129.76%, elasticity of 1.04×10^{-2} Kgf/mm^2, water absorption of 191%, solubility of 79%, water vapor has a five-day shelf life at room temperature and a transmission rate of 1.647 g/h.m^2. The edible film was made by physical mixing, according to FTIR analysis, without the creation of new functional groups. According to the biodegradability test, the edible film might break down in two days. The antioxidant capabilities were enhanced as the content of Moringa extract increased. The use of Moringa leaf extract improved the effectiveness of the edible films in protecting food from oxidation.

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